NASA Aeronautics Research Institute

Functionally Tailored Multi-Component Composite Structures via Additive Manufacturing

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FY12 Seedling Phase I Technical Seminar

July 9-11, 2013

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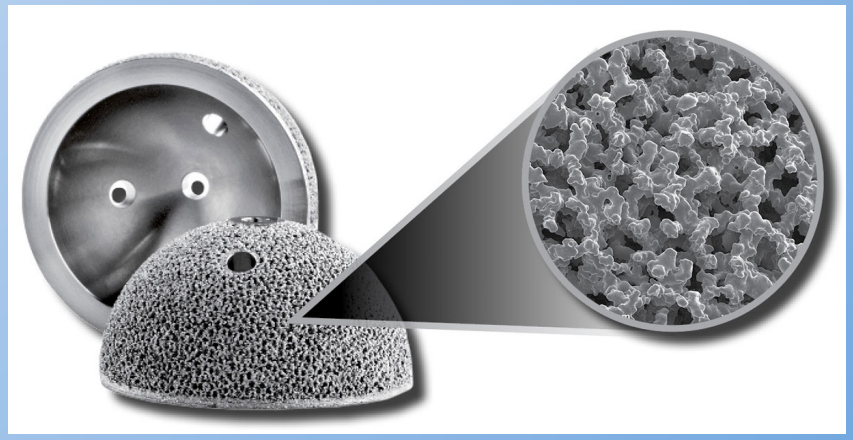
Introduction

Metallic foam structures can be fabricated through a variety of processes

- Open cell (reticulated) foams can be fabricated through established foaming processes for some specific alloys (Al, Cu, Zn)
- Closed cell (syntactic) foams can be made via powder metallurgy approaches for other alloys systems (Ti, Ni, Fe)
- Additive manufacturing opens up new possibilities for the creation of novel foam structures (periodic and random) across a very wide range of alloys (all the above)
- *This project will use additive manufacturing to create open cell "net structures" that can be infiltrated with another alloy to create a bi-metallic composite structure*

www.ergaerospace.com

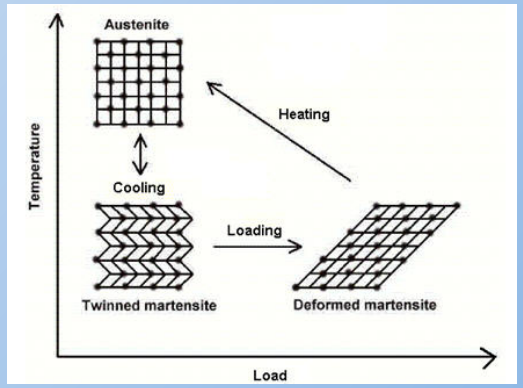


www.arcam.com

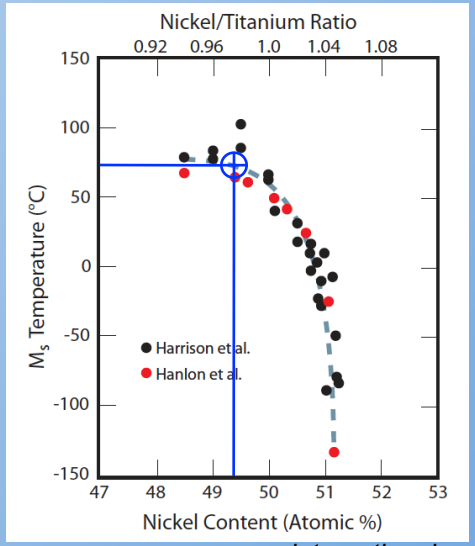
Introduction

The shape memory effect is well documented in certain materials and is currently being researched for a variety of applications

- The change in crystal structure from the high temperature phase (austenite) to the low temperature phase (martensite) is accommodated by twinning – the net volume change is zero
- Plastic deformation in the martensite is accommodated by "untwinning" the crystal
- Transformation back to austenite via heat treatment recovers the original crystal structure and original shape of the part
- *This project will exploit this phenomenon in order to introduce an internal load on a composite material system thus creating a controlled residual stress field in the structure*



www.keytometals.com

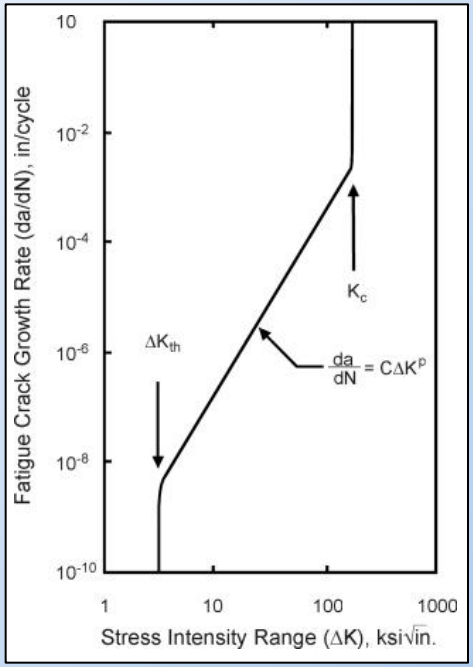


www.asminternational.org
SMST e-Elastic newsletter, January 2011

The Innovation

Stress fields within a structure can have a very significant impact on properties and performance

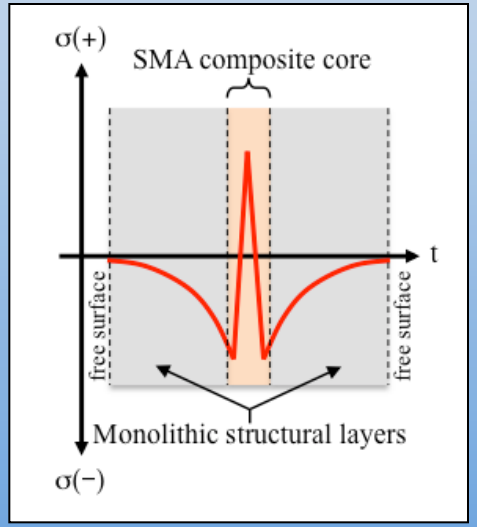
- Cracks tend to nucleate from a free surface and grow when stress levels exceed the threshold stress intensity factor (K_{th})
- Below the threshold level, a crack will not grow



Handbook of Damage Tolerant Design

Objective:

Create a unique bi-metallic composite structure with a carefully designed residual stress field that can be tailored to limit or eliminate the ability of a surface crack to propagate through the structure



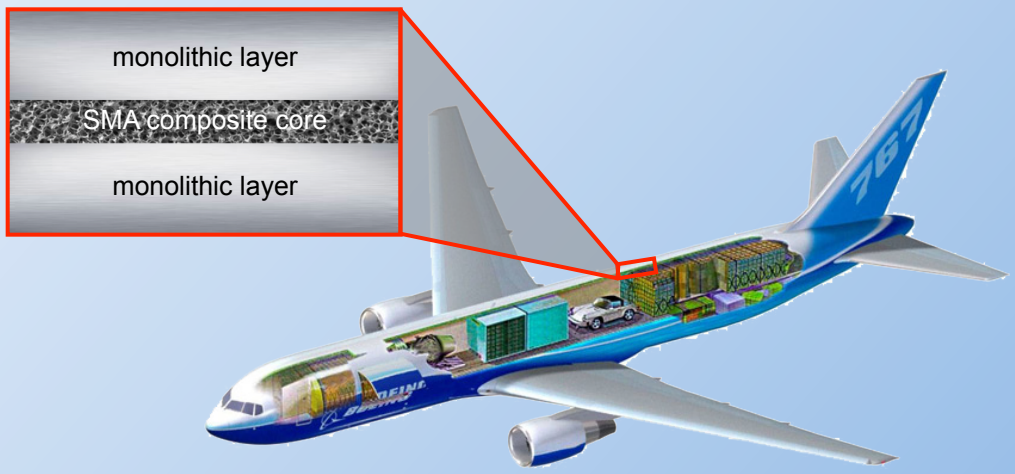
Impact

This concept could greatly impact the fatigue performance of structural aerospace components through crack closure and/or turning

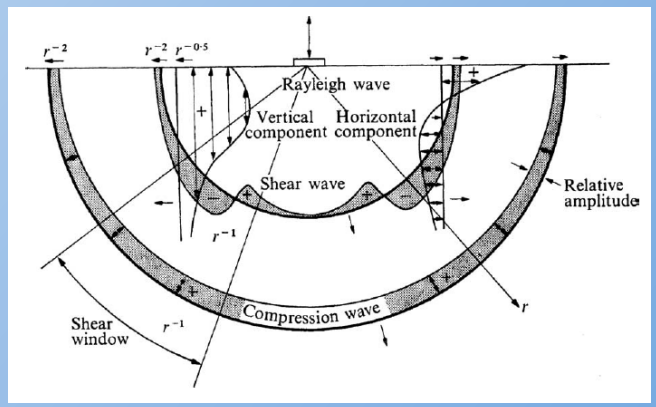
- Improves structural efficiency in damage tolerant-limited applications

Also has potential impact in anti-ballistic impact applications through shock wave disruption and/or attenuation

- MMOD shielding
- Armored tactical vehicles



www.boeing.com

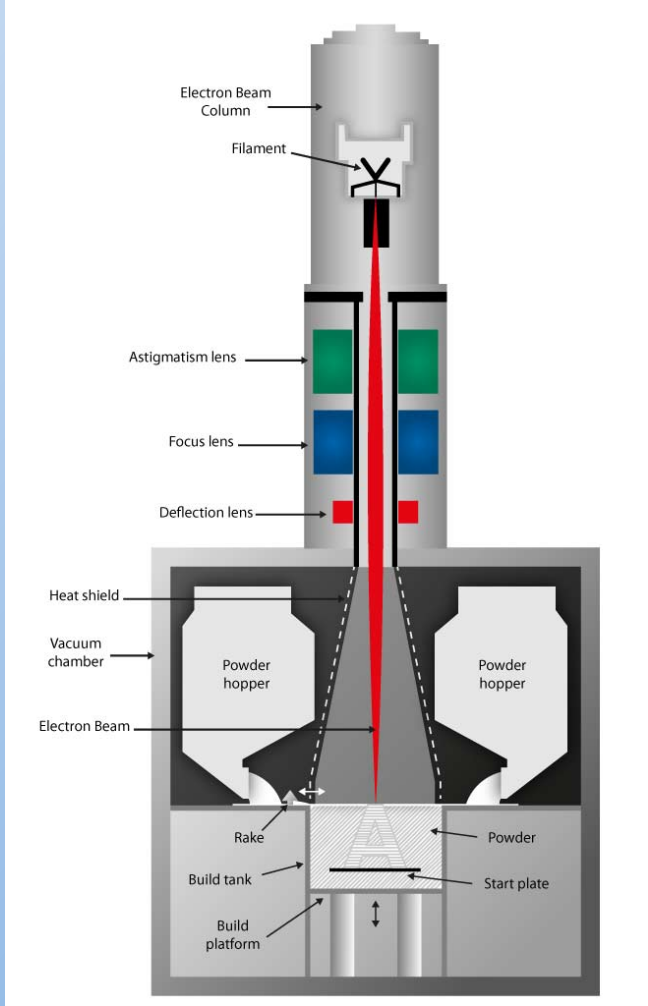


K.F. Graff, "Wave Motion in Elastic Solids", 1975 Clarendon Press, Oxford

Technical Approach – Processing

The Arcam electron beam powder bed additive manufacturing process was used to create the structures

- Fabrication done at W.M. Keck Center for 3D Innovation at the University of Texas at El Paso
- A thin layer of powder is spread over a substrate and an electron beam is used to melt and fuse the powders together
- The substrate platform increments downward and another thin layer of powder is spread over the previously fused layer
- The process is repeated until a three dimensional structure is created

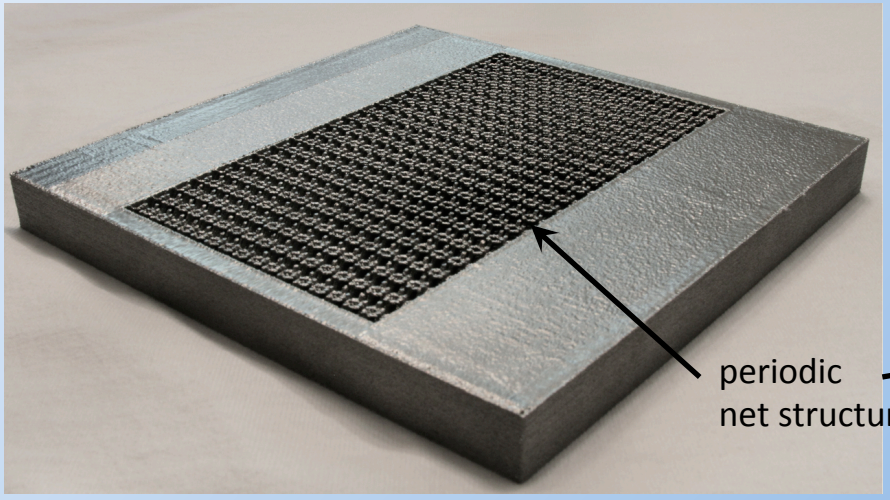


www.arcam.com

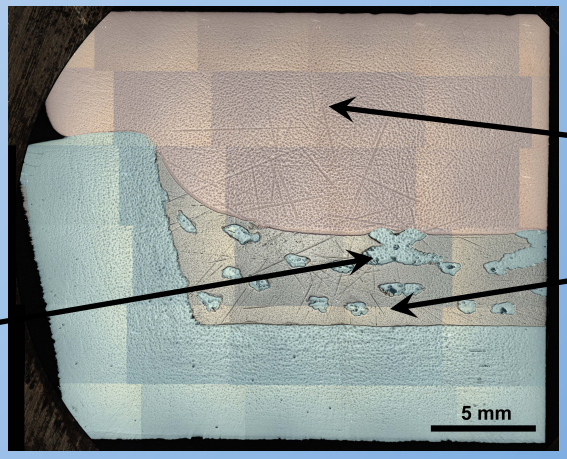
Technical Approach – Processing

Utilize additive manufacturing to create open cell net structures that can be infiltrated with a secondary alloy powder and hot consolidated into a fully-dense, multi-alloy structure

- Proof-of-concept with Ti-6Al-4V AM-fabricated structure infiltrated with commercially pure (CP) titanium and vacuum hot pressed to full density



metallographic cross section –
post consolidation



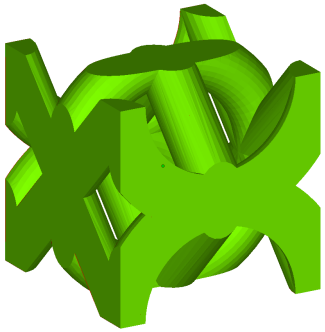
Results – Design

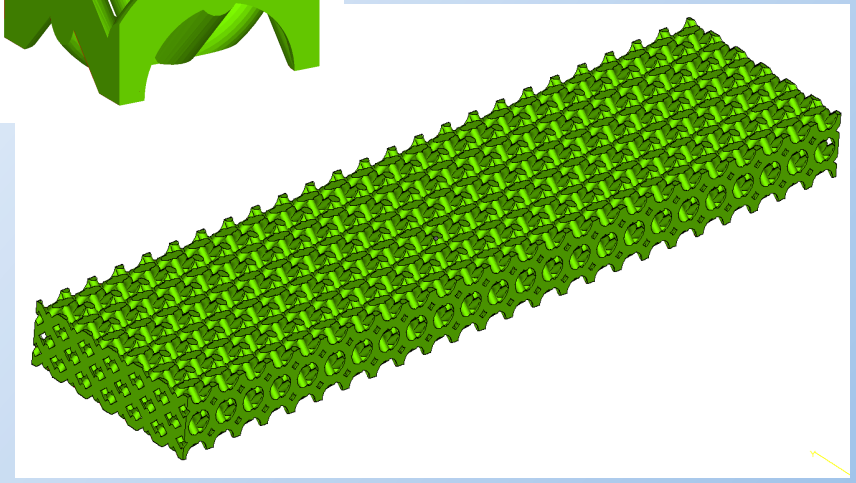
Periodic design

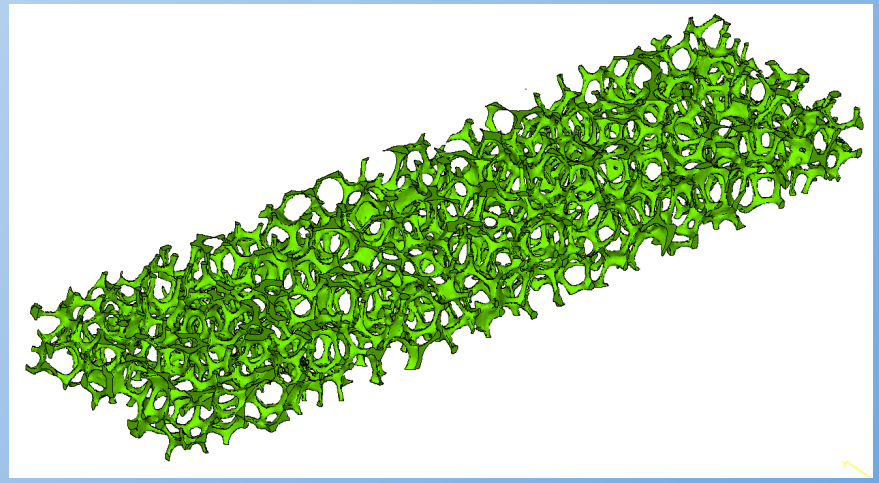
- Created unit cell using netfabb and SolidWorks software

Random design

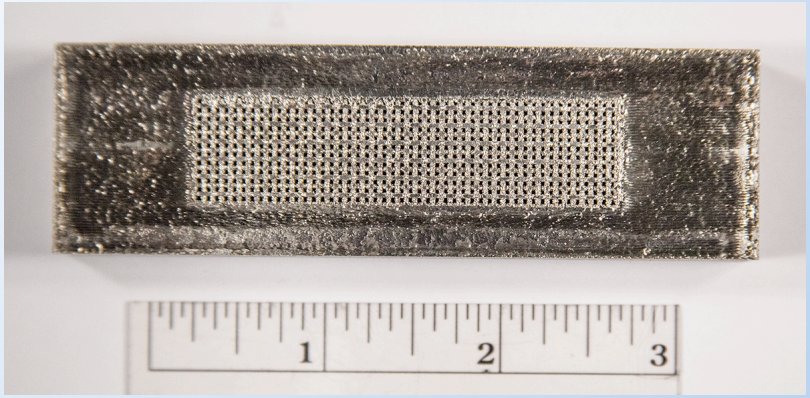
- Reverse engineered via computed tomography (CT) from commercially-available aluminum foam

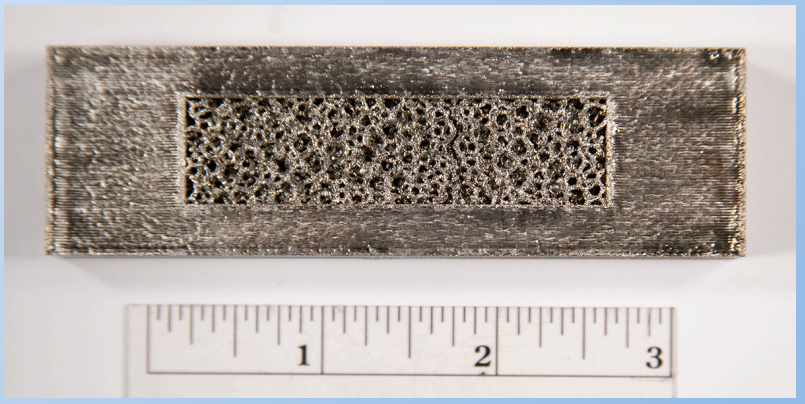


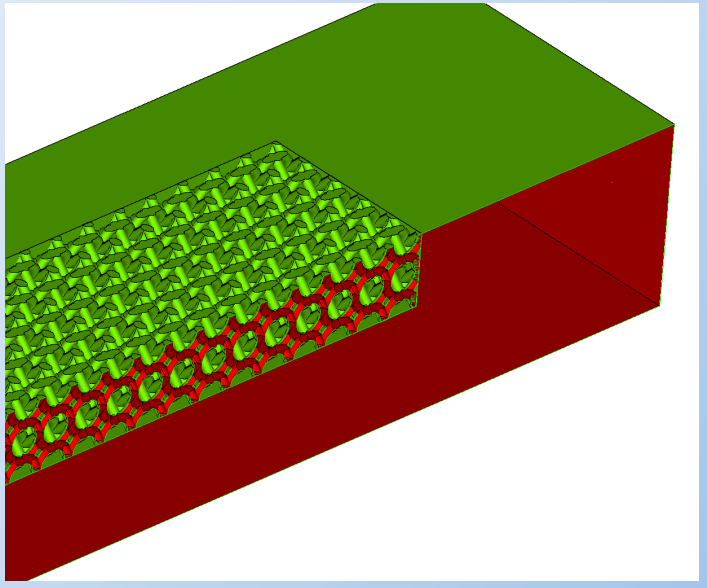


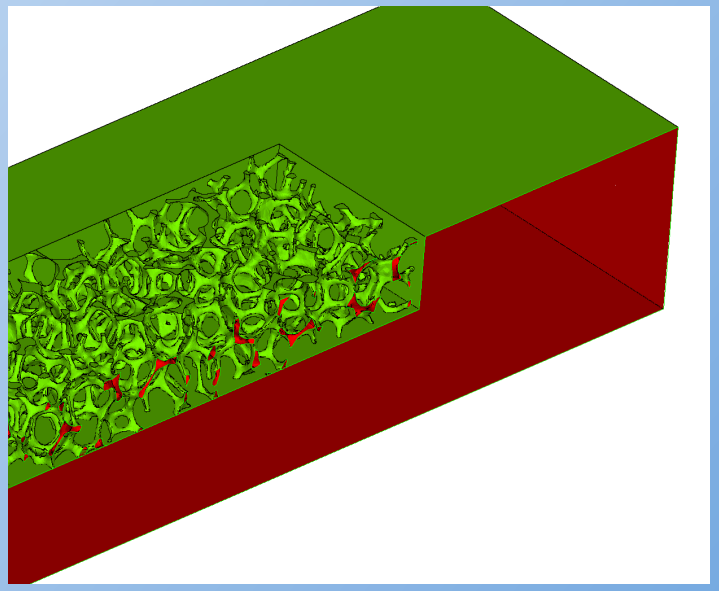


Results – Design









Results – Processing

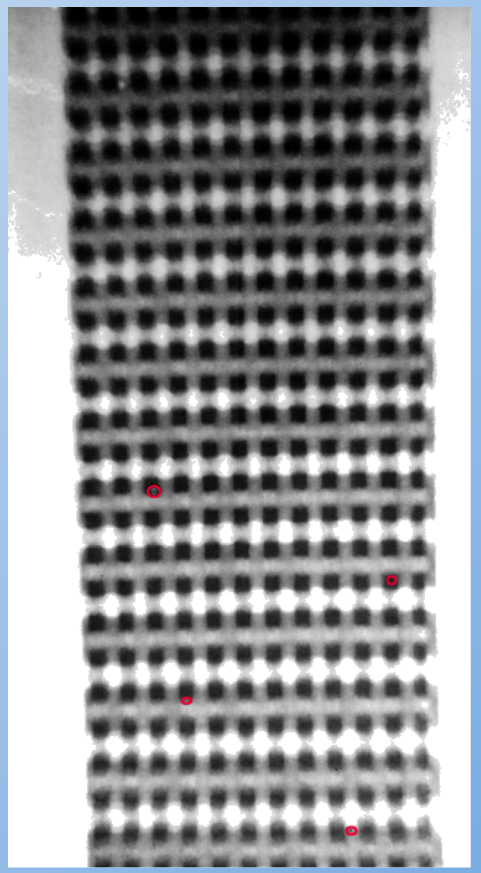
Processing route:

- NiTi powder vibrated into net structure voids
  - 50.7 at% Ti – 49.3 at% Ni; -140 mesh (-105 µm)
  - A_s = 68°C | A_f = 109°C | M_s = 78°C | M_f = 38°C
- A cover plate is added and the entire structure is vacuum hot pressed
  - 940°C for 4 hours at 1,000 psi
- The sample is trimmed to consistent dimensions using waterjet cutting
- Perform shape set heat treatment
  - 500°C for 15 minutes
- Cold roll to ≈ 5% reduction in thickness
- Perform memory activation heat treatment
  - 115°C for 15 minutes
  - Control sample evaluated in as-rolled condition

Results – Processing

Radiography of the vacuum hot pressed sample performed by Non-Destructive Evaluation Sciences Branch

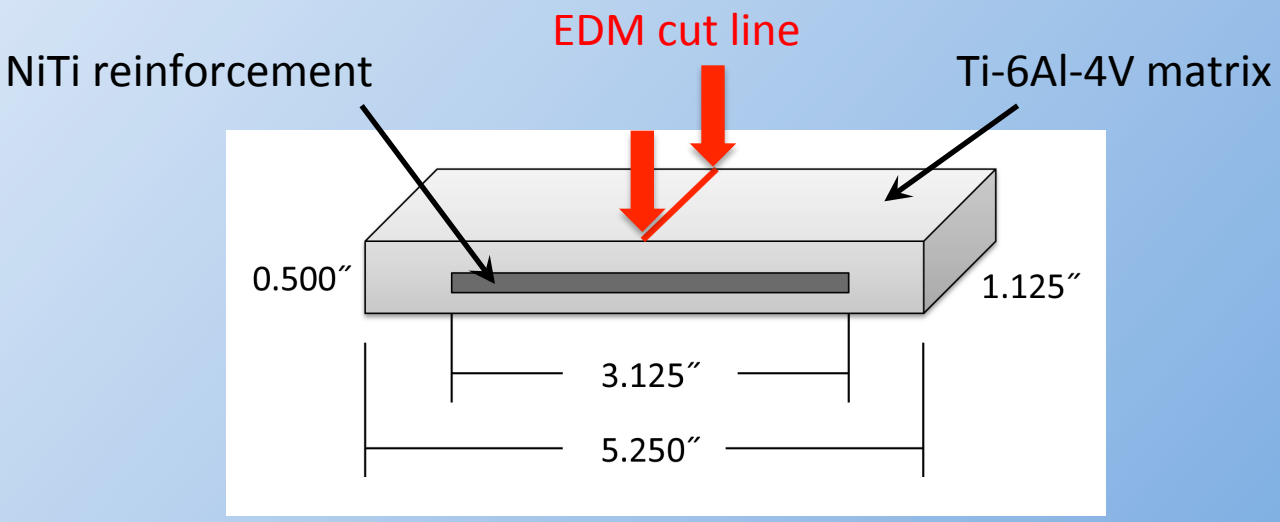
- No major voids indicating complete fill of the NiTi powder in the net structure
- Incidental porosity indicated by the red circles in the image
- Three-dimensional CT scan will be performed once samples are ready for residual stress testing



Results – Properties

Two dimensional residual stress profile is measured with the cut compliance method

- Wire electric discharge machining used to make an incremental cut through the thickness of the test coupon
- Strain gages placed adjacent and opposite the cut line measure surface strain as a function of cut depth
- Residual stress is calculated based on stress relaxation due to the cut



Results – Properties

Testing status

- Samples have been successfully hot consolidated
- Machining underway to trim down to appropriate size and adequately prepare the surfaces
- Shape set heat treatment + cold rolling + memory activation heat treatment will follow
- PR issued to Hill Engineering, LLC, Rancho Cordova, California for cut compliance testing

Dissemination

Internal

- This technical seminar
- Programmatic contacts at LaRC and at HQ
- Partnership in place from the beginning with MSFC as a mechanism to transfer the manufacturing know-how beyond LaRC

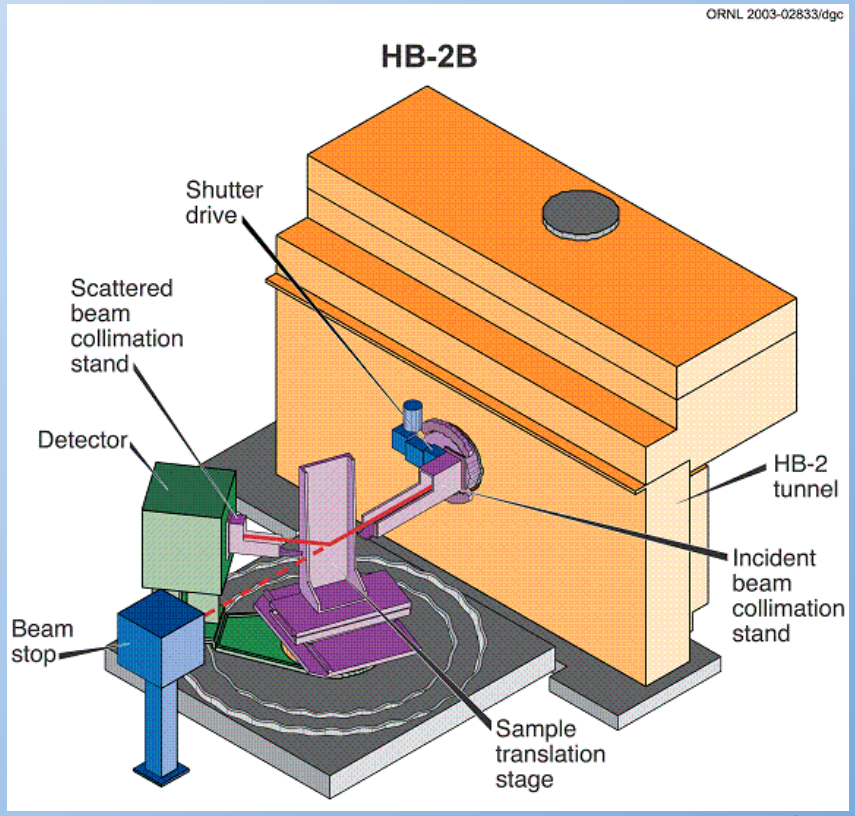
External

- Appropriate conference and/or journal publication(s)
- Contacts at major aerospace prime contractors – Boeing Research & Technology, Lockheed Martin Skunk Works
- Supporters at Army Research and Development Command at Picatinny Arsenal for armor applications

Next Steps

Neutron diffraction will be used to experimentally determine bulk three-dimensional residual stresses throughout the specimen

- Three days of beam time competitively awarded at Oak Ridge National Laboratory on High Flux Isotope Reactor, beam line HB-2B (Residual Stress Mapping Facility)
- Experiment scheduled for late August



www.neutrons.ornl.gov

Questions

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